HYDROTHERMAL APPLICATIONS OF HOT DRY ROCK TECHNOLOGY

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ABSTRACT

Within the past year, the US hot dry rock (HDR) geothermal energy research and development program has been redirected to encourage closer cooperation with the domestic hydrothermal industry. The Geothermal Energy Association has in turn recommended that one facet of a restructured HDR program should be the integration of HDR technology into the geothermal mainstream. This paper discusses a number of HDR developments in reservoir engineering, seismic science, tracer analyses, and reservoir modeling, and indicates how they might be applied to address hydrothermal issues. It is suggested that the integration of these and other HDR technologies into the geothermal mainstream might significantly contribute to enlarging the potential role of geothermal resources in the energy market of the 21st century.

INTRODUCTION

There is coming to be ever greater acceptance of the concept of a geothermal resource continuum such as that described by Sass (1995), with hydrothermal reservoirs that are being commercially exploited today at one end of the spectrum and true hot dry rock (HDR) resources, devoid of any naturally mobile fluid, at the other. In this vision of geothermal energy, the aims of hydrothermal and HDR research and development begin to meld into a common goal of mining the earth's thermal resources ever more completely and efficiently.

In October 1995, the United States Department of Energy, (DOE) in part to emphasize this commonality of geothermal interests, began a process of restructuring the US HDR Program by announcing that it was terminating its longstanding effort to move toward the commercialization of HDR. Instead the Department declared that HDR activities would be redirected to work with "private industry and other interested parties" to address the remaining HDR technical issues. In the preceding year, the DOE had issued a solicitation for an industry-led project to produce and market energy derived from an HDR resource and had entertained proposals from a number of bidders. Concurrent with the restructuring announcement, that solicitation was withdrawn and a directive was issued to dismantle the HDR field site at Fenton Hill, NM. With these steps, the DOE began a process of aligning US HDR research and development much more with the immediate interests of the commercial hydrothermal industry.

As a follow-up to the October announcement, the Geothermal Energy Association convened a panel of geothermal industry experts at the offices of UNOCAL Geothermal in Santa Rosa, CA in early December 1995. The group spent about a day reviewing worldwide HDR research, met in executive session, and then presented representatives of the DOE with a set of recommendations in regard to the direction of the restructured US HDR program (Wright 1996). The following statement summarized one of several recommendations developed by the industry panel:

> "HDR technology should be integrated into the mainstream geothermal industry. The industry can benefit from the technology developed in HDR research and, conversely, HDR development can benefit from hydrothermal technology."

The need for the application of new techniques to hydrothermal situations is clear. To quote Sass (1995), "...with present technology only a minuscule fraction of the heat in the rock is actually exploited during the life of a given system." This paper is being written to address the implementation of the GEA recommendation cited above, by suggesting ways that HDR technologies might be applied to take the geothermal industry beyond the "minuscule" geothermal energy extraction levels that are practical today.

BACKGROUND

By far the largest fraction of the world's accessible geothermal energy exists in the form of rock that is hot but is not in contact with the mobile fluid required to transport that heat to the surface for use by mankind. The technology to extract practical amounts of energy from this vast hot dry rock (HDR) resource was invented at the Los Alamos National Laboratory more than 20 years ago (Potter, et al 1974). Since that time, research and development work at a number of locations around the world has proven the technical feasibility of creating engineered reservoirs in crystalline rock, and then circulating water through such reservoirs to extract geothermal energy on a sustained basis. In particular, a series of flow tests conducted at the United States HDR test site at Fenton Hill, NM between 1992 and 1995, taken as a whole, provided a record of nearly a year of circulation under conditions essentially the same as those that would be implemented in the commercial production of energy from HDR (Duchane 1995).

The scale of flow testing at Fenton Hill was smaller than would be required for a viable commercial HDR facility, especially in today's highly competitive domestic energy market, and its duration was certainly not long enough to experimentally verify a long reservoir lifetime. Nonetheless, the flow test series at Fenton Hill demonstrated that useful amounts of energy can be routinely extracted from an HDR reservoir with only small net water consumption. The test revealed no geochemical problems arising from continued recirculation of the same fluid, and thermal drawdown of the reservoir was insignificant. During the final stages of testing, the ability to operate the HDR reservoir on a cyclic basis was demonstrated, thus highlighting the unique advantages that confined, rapidly rechargeable, HDR reservoirs may bring to applications such as load-following power generation (Brown 1996).

As part of the HDR program, significant technical capabilities were developed in resource identification and evaluation, drilling, hydraulic fracturing, fracture location and characterization, reservoir engineering, logging tool development and application, reservoir development and operation, and reservoir modeling. Many similar technological developments occurred in the commercial hydrothermal industry in the same time frame, but generally with a somewhat different emphasis. In a few cases, such as drilling and logging tool development, transfer of specialized HDR technologies to the private sector has taken place via the service companies involved in various parts of the HDR program. To a large degree, however, the specialized technologies developed as a result of HDR research in the US and elsewhere, have not yet been applied to the development, operation, and understanding of hydrothermal reservoirs.

SOME POTENTIAL APPLICATIONS OF HDR TECHNOLOGY TO HYDROTHERMAL SITUATIONS

In today's highly competitive energy marketplace, it is imperative that the best available technical knowledge be employed to identify, extract, and utilize geothermal resources. The application of HDR technologies to the solution hydrothermal problems should be an effective means of improving the competitive position of all geothermal resources in world energy markets. Some specific technology areas where HDR experience and expertise might be immediately applied to hydrothermal problems are discussed in more detail below:

Reservoir Engineering

Hydraulic fracturing, pressure management, and reinjection are the core reservoir engineering strategies employed in creating and operating HDR reservoirs (Duchane 1995). Hydraulic fracturing is widespread in the petroleum industry, but to date has been of distinctly minor importance in the exploitation of hydrothermal resources. In the United States, except perhaps for proprietary applications, hydraulic fracturing has been employed primarily as a research and analysis tool to evaluate reservoir characteristics (Hickman and Zoback 1996). The Japanese have attempted to use hydraulic fracturing to increase production from hydrothermal reservoirs with mixed results (Kizaki and Sato 1996). It seems likely, that by combining the expertise developed as part of HDR research and development with the strong conventional reservoir engineering experience of the United States geothermal industry, it might be possible to apply hydraulic fracturing to existing wells which are either dry or marginal producers and thereby bring value to what are now effectively "stranded" geothermal assets.

Reinjection has been widely practiced in the geothermal industry for many years. In addition to being a means for disposing of waste geothermal fluid, injection is becoming an important factor in sustaining the productivity of hydrothermal fields (Gambill 1992). Nonetheless, nowhere have fluid injection techniques been employed or studied to the extent that they have at HDR research sites worldwide. The major reason for this is, of course, that essentially all of the production from an HDR system is dependent on continuous reinjection. In practice, Los Alamos HDR researchers have typically utilized fluid injection pressure as the primary control variable in operating their HDR system (Duchane 1995). Because HDR reservoirs are relatively small and fully contained, the effects of changes in injection conditions are rapidly reflected at the production wellhead. As with hydraulic fracturing, it would seem obvious that melding the intensive injection experience of the HDR Program with the developing injection interests of the hydrothermal community could lead to more efficient utilization of hydrothermal resources in the near term. In this regard, the large scale project that will entail injection of water from the Clearlake, CA area into The Geysers steamfield (Dellinger 1996) might provide the ideal opportunity for the implementation of a joint hydrothermal/HDR injection study.

Seismic Location and Surveillance Technology

The microseismic events associated with the creation of an HDR reservoir provide by far the best indication of its size, shape, orientation, and location (House 1987). For this reason, the detection and location of microearthquakes has been the object of intensive work by HDR researchers around the world for more than 20 years. Seismic detection installations have been a key component at every HDR field site, and a vast amount of data has been collected. A wide variety of techniques have been applied to analyze the seismic signals. While it is now possible to use seismic data to determine the general outlines of HDR reservoirs, the work to elucidate the details of reservoir structure from seismic information has only recently begun to make progress (Roff, et al 1996). Cooperative efforts, such as the MTC project sponsored by the Japanese (Niitsuma 1996), are now being implemented to provide data bases derived from a variety of sources for the evaluation and comparison of the various seismic techniques and models that have been developed worldwide.

The association of seismicity with commercial energy extraction has been well documented in a wide variety of petroleum and geothermal settings. The DOE has sponsored a microseismic monitoring project at The Geysers for a number of years, both to document natural seismicity and seismic events related to fluid withdrawal, and to gain a better understanding of the microseismicity associated with reinjection (Majer, et al 1996). Although there have been only tentative moves toward cooperative HDR/hydrothermal seismic projects, the seismic technology developed under the HDR Program in the United States has been applied in cooperation with the petroleum industry to evaluate a variety of oil and gas reservoirs (Rutledge, et al 1994). Integration of HDR microseismic technology into the hydrothermal seismic program would appear to offer great potential benefits to the geothermal industry by bringing the full-range of microseismic detection and analysis resources to bear on hydrothermal problems.

Tracer Development and Application

Tracers have routinely been used both in hydrothermal and HDR reservoirs to elucidate the flow paths of injected fluids and to gain more understanding of the physical characteristics of geothermal reservoirs. While there is a considerable body of tracer expertise and experience in the hydrothermal industry (Rose and Adams 1996, Adams 1996), there may be unique contributions that can be made based on HDR experience. Tracers have been used in HDR systems to estimate the reservoir fluid volume (Callahan 1996) - a task which is much simpler in a relatively small, confined system such as an HDR system than in a large hydrothermal system. In addition, thermally reactive tracers have been evaluated for use in determining the temperature drawdown pattern in HDR systems (Robinson and Birdsell 1987), but, unfortunately, there has been no opportunity to test these tracers in actual HDR reservoirs. Finally, another paper at this conference presents a concept involving the use of multiple tracer forms simultaneously, with a non-reactive tracer serving as an internal standard while thermally reactive and adsorbent tracers are utilized for determining temperature and surface area characteristics of a reservoir (DuTeaux and Callahan 1996). The complimentary tracer expertise of the hydrothermal and HDR communities provides an opportunity for the formulation of joint experiments which could markedly increase the utility of tracers as reservoir evaluation tools.

Reservoir Modeling

GEOCRACK is a fully coupled fluid flow/rock deformation/heat transfer model developed at Kansas State University for predicting the performance of open, multiply-jointed HDR reservoirs under a variety of operating conditions. Actual performance data from the Fenton Hill HDR system has been used to test and modify GEOCRACK so that the model now accurately replicates the production-flow and tracer behavior observed at Fenton Hill during the flow testing sequence of 1992-1995 (DuTeaux, et al 1996). A number of other HDR modeling studies have been conducted both in the US and elsewhere. For example, Robinson (1990) developed codes to simulate the pressure transient behavior of the Fenton Hill HDR reservoir, Robinson and Kruger (1992) simulated reservoir thermal performance based on volume and fracture spacing considerations, and Kruger (1995) applied modeling to calculate the thermal drawdown resulting from flow tests of HDR reservoirs around the world. Although HDR models may have been developed specifically for engineered reservoirs, the broad geothermal elements they typically incorporate should make them useful in evaluating specific characteristics of hydrothermal reservoirs, especially liquid-dominated, fracture-controlled systems. In this way, HDR models might serve to complement and enhance the extensive hydrothermal modeling efforts already underway.

SUMMARY

A large body of unique geothermal knowledge has been created as a result of more than twenty years of research and development of HDR. Although some technology transfer has taken place via geothermal service companies, the HDR and hydrothermal research communities have for the most part followed parallel but separate paths. In view of the recent DOE mandate for a more unified approach to government-sponsored geothermal research and development, the time is right to join these paths to the benefit of all concerned. Numerous opportunities exist for the fruitful transfer of HDR technology to the hydrothermal area. Working together, the best of hydrothermal and HDR technologies can be combined to assure continued US leadership in geothermal energy development and implementation around the world.

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